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Research of luminophores afterglow under influence of pulsed X-ray radiation of nanosecond duration

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Abstract. The work describes an investigation of afterglow of various luminophores under influence of pulsed X-ray radiation of nanosecond duration. As a source of radiation a pulsed X-ray "Yasen 01" apparatus is applied. Maximum impulse current of an X-ray tube is 300 A. Maximum electron energy is 120 keV. Half-height pulse duration of an X-ray burst is about 30 ns. A pulse repetition rate is up to 4 kHz. Two types of X-ray luminophores based on gadolinium oxysulfide $Gd_2O_2S:Tb$ and cesium iodide CsI:Tl have been investigated. The novelty of the work is use of a fast-acting solid-state semiconductor photomultiplier. It allows recording changes of luminophores luminosity in the nanosecond time range. The photomultiplier is characterized by having two discreet outputs for measuring quickly and slowly time-changing light flows. Presence of two signal outputs allows recording changes of luminophores luminosity both during fast nanosecond excitation and during long-time afterglow. Obtained data about the nature of afterglow of investigated luminophores makes it possible to select the best one for use in conjunction with a pulsed X-ray apparatus with a high pulse repetition rate.

1. Introduction

Different types of X-ray luminophores are used for creating modern digital flat panel detectors of X-ray radiation. Afterglow duration is one of the most important features of luminophores. This feature gains particular importance when X-ray visualizing devices are being irradiated by bursts of nanosecond pulses. In this case the overall duration of dose accumulation by the detector is several times longer than the duration of the direct X-ray effect on the luminophore. As the result, most of the time the recording system registers not only the desired signal during the luminophore afterglow, but also the intrinsic circuit noise. It reduces the signal/noise ratio and lowers the image quality significantly.

It is known that X-ray luminescence of most materials consists of two components: the fast one (tens of nanoseconds) and the slow one (tens, hundreds of microseconds). The slow component carrying 80% of the radiant energy is used while creating X-ray visualizing devices. Thus it is possible to implement the constant luminophore glow mode while optimizing pulse generation frequency. The optimal pulse-repetition rate depends on the luminophore afterglow duration, i.e. fading of the slow component. This X-ray luminophore excitation mode retains a high signal/noise ratio of the recording system and ensures obtaining images of high quality. These data are of high importance while operating pulse apparatuses in medical diagnostics for minimizing patient dose exposure.

There are investigations which include studying pulse X-ray luminescence [1]. But the recording system used there and based on the photomultiplier FEU-87 (a Russian abbreviation) and the oscilloscope «Bordo» with the bandwidth of 150 MHz does not allow to register pulses of nanosecond duration. As long as there are no registrars of X-ray luminophore optical radiation of nanosecond duration, developing such a device is a relevant objective.

Using the solid photomultipliers SensL’s C-Series low-light sensors makes it possible to solve this problem within the investigation [2]. These devices consist of numerous photosensitive in-parallel microcells with typical dimensions of 10 to 50 micrometers. Meanwhile the surface area of the photodetector can be up to 36 mm^2. It ensures high sensitivity of the device and lowered output impedance. The signal from the device can be transmitted to the measuring system through the 50 Ω cable without preamplification. Since there is no need in an intermediate amplifier it widens the frequency range of measured signals. The device allows to register light pulses within subnanosecond range. For these purposes it has a separate output, which makes it possible to register light pulses of 0.6 to 3 ns duration. The additional advantage of this device is its supply voltage which does not exceed 30 V.

2. Description of the experimental setup

The flow diagram of the experimental setup is given in figure 1. The “Yasen-01” apparatus is used as the X-ray radiation source (1) [3]. The device has the following parameters: the pulse voltage is 120 kV, the X-ray pulse-repetition rate is up to 4 kHz, the X-ray tube pulse current is up to 300 A, the current pulse duration is up to 30 ns. The recording equipment is in a lightproof case (2). The recording system consists of a screen covered with luminophore (3), a collecting lens (4) and a C-Series sensor of MicroFC 60035 type (5). The sensor is powered by a stabilized supply source with the voltage of 26 V (not shown in the figure). The current signal from the sensor is transmitted to the input of the oscillograph (6) through a series resistor of 50 Ω with the help of the RK-50-3-12 (a Russian abbreviation) cable.

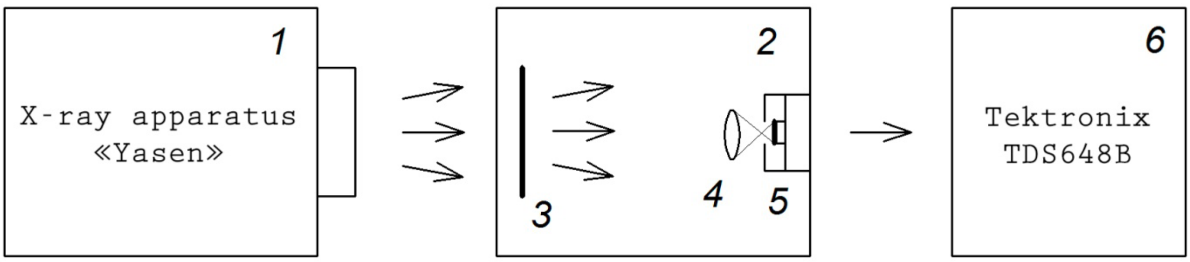

Figure 1. The block diagram of the experimental setup.

3. Test results

The sensor used makes it possible to visualize the luminophore glow intensity, when it is under the influence of X-ray flares with duration of 30 ns. We suppose that the duration of the X-ray radiation corresponds to the current duration of the “Yasen-01” apparatus tube. It is obvious that energy spectrum of the radiation is inhomogeneous as the result of the voltage drop at the tube during the current pulse. Whereas the active energy defined by the half-value layer is 47 keV. The combined curves of X-ray tube current and Gd_2O_2S:Tb luminophore glow intensity are given in figure 2a. When the excitation pulse ceases, it does not lead to simultaneous stabilization or the beginning of luminophore glow lowering. The building-up of luminophore Gd_2O_2S:Tb glow persists after the excitation pulse ceases, but the increase rate of glow intensity gets lower.

The authors of the investigation [4] observed such inertial luminophore building-up during the period of 0.2 to 0.6 μs. This effect appears only when the luminophore temperature rises from 78 to

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170 K and higher. The glow intensity increases up to 30%. They explain the time of inertial glow building-up by electron lifetime on P-level up to its thermal release.

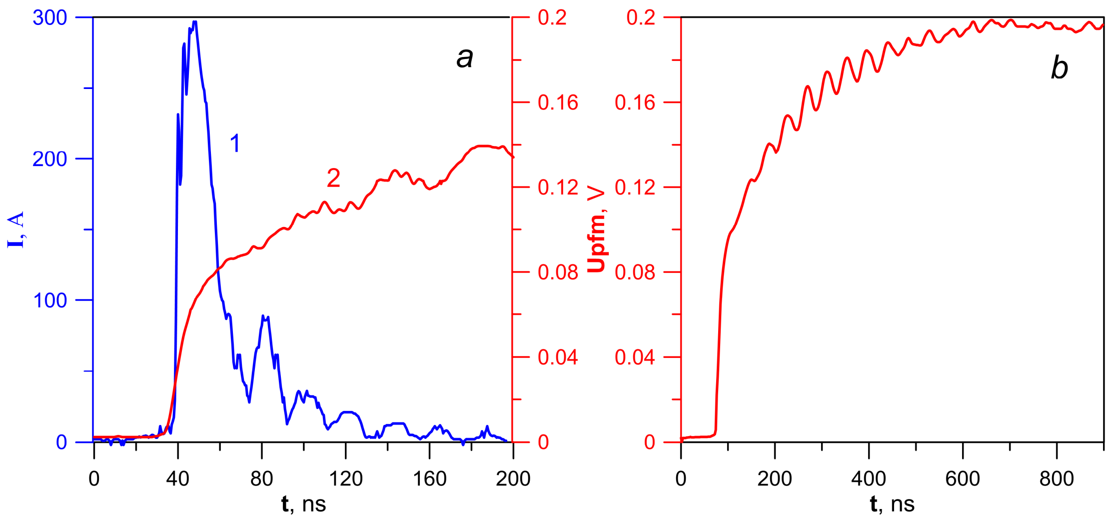

Figure 2. (a) The process of luminophore excitation, where: 1 – X-ray tube current; 2 – luminophore glow intensity. (b) The effect of luminophore glow intensity increase after its excitation stops.

Also in figure 2b you can see the curve of luminophore glow intensity increase in a different time scale. Judging by this figure we can conclude that in our case luminophore glow intensity increases exponentially no less than by two times during the period of about 0.5 μs after the excitation process stops. It is much more than in the investigation [4].

But the main test subject in this paper is studying the afterglow processes of different luminophore types. The X-ray apparatus “Yasen-01” operates in the nanosecond pulse mode with the repetition rate up to 4 kHz, which demands searching an optimal luminophore type in all operating modes. The luminophore glow excitation during tens of nanoseconds and its consequent afterglow within a millisecond range makes it possible to reduce the radiation dose during X-raying.

In figure 3 we present the curve of the luminophore Gd_2O_2S:Tb glow intensity when the X-ray source operates at the frequency of 2 kHz as an example. Judging by the curve shape we can conclude that starting from a definite pulse repetition frequency, the luminophore glow intensity gains a constant component. There occurs luminophore glow accumulation effect from pulse to pulse. Even though there appears a constant component of glow, the relative duration of the radiation effect on luminophore does not exceed 10000 in this experiment. Further rise of pulse repetition frequency will lead to subsequent rise of glow intensity and lowering of its pulsation level.

The afterglow of CsI:Tl and Gd_2O_2S:Tb luminophores are shown in figure 4. These luminophores have a vital difference in intensity and glow time after X-ray pulse excitation of nanosecond duration. The afterglow of the luminophore Gd_2O_2S:Tb is about 1.5 ms, while for CsI:Tl this time is less than 0.5 ms. Using the luminophoreCsI:Tl as an intensifying screen is justified for an X-ray apparatus with the X-ray pulse frequency of higher than 5 kHz. At such frequencies the luminophore glow will be accumulated from pulse to pulse and the ratio signal/noise will rise. As for the luminophore Gd_2O_2S:Tb accumulation will occur at frequencies of higher than 1 kHz. Using this luminophore is the most suitable for the “Yasen-01” apparatus, as its operating pulse repetition frequency is lower than 5 kHz.

The reliability of the obtained results is checked by comparing the MicroFC 60035 sensor readings with data from the vacuum phototubes F10 (a Russian abbreviation). To increase sensitivity a matrix of 7 in-parallel phototubes was assembled. The curves of luminophore afterglow, obtained from two different detectors in microsecond range, differ in amplitude, but are of the same shape. Therefore we can conclude that the obtained results are reliable.

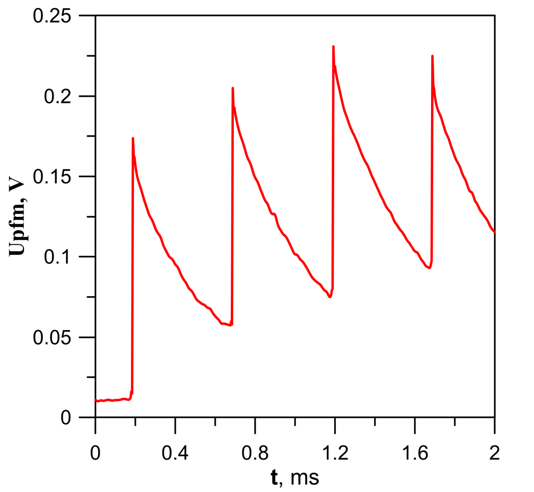

Figure 3. Luminophore glow intensity accumulation in frequency mode.

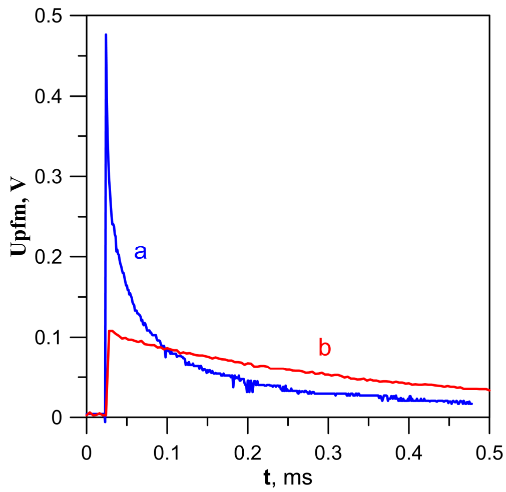

Figure 4. Comparing the afterglow of CsI:Tl (a) and Gd_2O_2S:Tb (b) luminophores.

4. Discussion and Conclusion

Due to its parameters the sensor MicroFC 60035, used in this investigation, made it possible to study not only the luminophore afterglow process, but also their excitation in nanosecond range. It is not quite clear why the glow intensity increases after the radiation effect on the luminophore stops. So in the investigation [4] such processes are caused by thermal effects. The authors of this paper affirm, that the glow increases after the effect on the luminophore stops only at higher temperatures. Possibly it is connected with phonon-electron influence, but the way it works is unclear.

As long as the pulse duration is short in our case X-ray radiation is present for not a long period of time within the overall exposure time. The luminophore afterglow duration exceeds its excitation time by thousands of times. To increase the luminophore glow intensity it is necessary to increase the pulse repetition frequency. We need to point out that the high-voltage power supply of the pulse nanosecond X-ray apparatus “Yasen-01” is completely made of solid-state elements. As a switch we use SOS-diodes, the operating frequencies of which can reach several MHz in the pulse burst mode [5]. At the frequency of 20 kHz one should expect almost continuous glow of both Gd_2O_2S:Tb and CsI:Tl luminophores with insignificant pulsation. Meanwhile the relative duration of the X-ray radiation effect will not exceed 1000. It opens possibilities for reducing the X-ray radiation dose received by the target and for shortening the exposure time. High frequency will conduce to fast dose accumulation, which allows to register dynamic objects.

The results we obtained during the course of our investigation also demonstrate the possibility and advantages of using modern solid-state photomultipliers for measuring luminophore glow intensity. Using them makes it possible to optimize the performance of pulse X-ray apparatuses. High sensitivity together with fast operation speed and operability of the applied sensor make it a perfect device for settling such issues.

References

[1] Shmurak S Z, Kedrov V V, Klassen N V and Shakhray O A 2012 Pulsed X-ray luminescence of composites made of inorganic particles and organic luminophores*Techn. Phys. Let.* **38** 10
[2] The Product catalogue of SensL/ Access mode: http://sensl.com/products/c-series/, free. (Access date 16.04.2018)

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[3] Bayankin S N, Mozharova I E, Kuznetsov V L, Korzhenevskiy S R and Komarskiy A A 2015 *Vestnik rentgenologii i radiologii* **2** 42
[4] Meleshko AA 2009 *Time-resolved optical spectroscopy of Csl(Tl). Thesis for a candidate degree in physico-mathematical sciences*(Tomsk: Tomsk Polytechnic University) 125 p
[5] Wang G, Su J, Ding Z, Yuan X and Panat Y 2013 *Rev. Sci. Instr.* **84** 125102